Knowledge Analysis Outside the STEM Classroom

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Abstract: Knowledge Analysis has proven an important and useful set of methods for characterizing the constituent parts and processes of human reasoning and learning. However, its application has largely been limited to knowledge in a narrow selection of STEM domains, limiting the generalizability of its findings. This symposium draws together scholarship operating within the Knowledge Analysis tradition to investigate reasoning and learning in domains outside of STEM classroom subjects. In doing so, each paper explores the affordances and limitations of Knowledge Analysis to shed light on significant questions in their respective domains of knowledge, including: restorative justice practices, the ethics of drone warfare, undergraduate course design, and urban planning. By further expanding the use of Knowledge Analysis to include non-STEM subjects, we hope to raise important questions and offer richer and more generalizable views of knowledge and learning relevant to both STEM and non-STEM domains.

Keywords: Knowledge in Pieces, ideology, qualitative methods, education

Symposium overview

Knowledge Analysis (KA) is a central pillar of the learning sciences. Following diSessa, Sherin & Levin (2016) we use KA to refer to Knowledge in Pieces and related theoretical frameworks used to investigate human cognition through attention to relatively small units of meaning that are called up, revised, and re-organized through processes of perception and reasoning. Insights from within the KA tradition have reshaped our expectations for what novice ideas look like, emphasizing the role of contextually cued intuitive knowledge resources rather than fully coherent naïve theories (Smith, diSessa, & Roschelle, 1993). Scholars working in this tradition have built our understanding of how reasoning and learning occur at the micro level as well as over longer timescales (diSessa & Sherin, 1998). And, building on these insights, KA has provided a foundation for the design of learning environments that take advantage of learners' intuitive understandings to facilitate learning processes (Hammer, 1996).

However, with a few notable exceptions (Jansson, Wendt & Åse, 2013; Markauskaite & Goodyear, 2014; Philip, 2011), KA has been applied to a relatively narrow range of knowledge domains. Physics has been most prominent among these (e.g. diSessa, 1993; Hammer, 2000; diSessa & Sherin, 1998; Smith et al., 1993). Moreover, while Knowledge Analysis has been applied outside of physics as well, to math, biology, chemistry, and computer science, for example, it has remained predominantly confined to STEM subjects.

While these studies have offered important insights, the similarity of subject matter in the existing body of KA literature is also limiting. First, it represents an empirical limit on our understanding of intuitive knowledge and learning processes in other domains of human knowledge and practice. It also represents a theoretical limitation. Similarity in domain content can obscure the distinction between features of knowledge organization and transformation that reflect general principles of human cognition, and those that reflect particularities of certain types of content. Moreover, the particular emphasis on STEM has often reified a view of scientific knowledge as objective and value neutral, obscuring the role of values and affect in the process of constructing meaning. In order to continue to deepen our understanding of human cognition, learning scientists would be well served to explore the use of a KA approach for illuminating a wide range of learning contexts and content.

This symposium draws together scholarship operating within the Knowledge Analysis tradition to investigate reasoning and learning in domains that have previously been little explored within this framework. In doing so, each paper explores the affordances and limitations of KA to shed light on significant questions in their

respective domains of knowledge. Anderson does so in the context of the implementation of restorative justice practices in schools. Linking educators' conceptualizations of the nature of restorative justice to their ability to implement it effectively, Anderson identifies a set of cognitive frames that seem to foreground and background different element of restorative justice practices--and put educators more or less at risk for common 'misconceptions.' Gupta and Philip investigate the role of taken for granted assumptions in reasoning about ideologically charged content--specifically, the ethics of drone warfare. They use a methodological approach at the intersection of Knowledge in Pieces and Interaction Analysis, emphasizing the mutual benefits of connecting these two approaches. Markauskaite, Kali and Goodyear use the lens of mental resources to investigate how university academics make and explain their decisions about curriculum design and teaching. Synthesizing insights from three studies in which they explored the nature of mental resources on which university academics naturally draw in their pedagogical sensemaking in different contexts, they present an integrative view about the grounded nature of teachers' pedagogical resourcefulness. Finally, Hjorth investigates undergraduate students' reasoning about data in the domain of urban planning. He examines the continual fine-grained changes in students' interpretation of data and describes how students shift their goals towards more 'ideologically acceptable' versions, as they participate in an agent-based simulation classroom activity.

In addition to their empirical contributions, these papers also offer valuable insights about the nature of knowing and learning more broadly. Like prior Knowledge in Pieces work, the papers highlight ways that knowledge is called upon flexibly. They counteract assumptions that educators' approaches to practice are rooted in singular theories of instruction or discipline (Anderson; Markauskaite, Kali & Goodyear), and demonstrate how learners may offer divergent or even contradictory statements depending on context or framing (Anderson; Gupta & Philip; Hjorth). Each characterizes relevant knowledge structures in a slightly different way, identifying primitives and more complex structures using approaches that build on existing theorizing to account for the nature of each domain and context. At the same time, these papers raise important methodological, conceptual and practical questions relevant to both STEM and non-STEM domains. For example: What challenges are posed by investigating knowledge in domains without clear boundaries, or measuring learning when there is not a clear 'right' answer? What are ideological 'features' of a phenomenon, and do we attend to value-laden features in a different way than non-value-laden features? How can we design and facilitate learning environments that support reasoning about issues of social importance in all their complexity? Olivia Levrini will act as discussant for the symposium, commenting both on the papers' individual merits and setting the stage for what we hope to be a lively discussion on these cross-cutting themes.

What are restorative justice practices? A cognitive account in elements and frames

Eleanor R. Anderson

In this analysis, I seek to investigate educators' understandings of Restorative Justice Practices (RJP), an approach to school discipline and culture that eschews exclusionary punishment, and emphasizes problem solving and positive relationships. Like all learners, educators make sense of new ideas—including new programs and policies—through the lens of their existing knowledge (M. G. Sherin, 2002; Spillane, 2004; Spillane et al., 2002). Given that programs designed for educational reform are frequently built around novel ideas regarding content, instruction, or philosophy, this makes educational reforms highly susceptible to misunderstanding (Coburn, 2005; Spillane, 2000, 2004).

RJP is an umbrella term for a set of specific practices, as well as a philosophy that can be applied to a broad range of situations. Some RJP advocates fear that many teachers hold 'punitive mindsets,' requiring a radical shift in perspective to understand RJP fully. However, analyses of other knowledge domains have revealed that seemingly coherent misconceptions may also reflect relatively simple differences in the organization of smaller pieces of knowledge (diSessa & Sherin, 1998). Thus, an empirical investigation of teachers' constellations of ideas about discipline and restorative justice is needed in order to assess (and facilitate) the task facing school leaders seeking to implement RJP.

I draw from interviews with 26 staff members at Rustin HS, an urban public school adopting RJP. The sample includes teachers, administrators and security staff plus two RJP experts who were supporting the school's implementation process. Following Hammer et al. (2005), I characterize educators' conceptions and misconceptions of RJP in terms of cognitive elements and frames.

Beginning with short 'en vivo' codes I identified 250 unique elements that educators attended to in characterizing a particular disciplinary response as exemplifying RJP or not, ranging from named practices, to sample conversational elements, to usage situations, to goals, and beyond. Next, I identified four cognitive frames

that educators used to articulate the essence of RJP more broadly. Each represents a different way of distilling what makes RJP distinctive: their Objective, the Alternative (i.e. what they are not), their Component Parts, and their philosophical Lens. Each of these frames was used both by educators who were relative novices with regard to RJP and also by local experts, invoked sometimes one at a time, often in combination.

Next, I sought to understand how different frames might offer different cognitive affordances and constraints with respect to teachers' growing knowledge about RJP. Using the 30 most commonly invoked elements, I calculated the frequency with which each appeared in a response utilizing each of the four frames, finding distinctive patterns of elements foregrounded and backgrounded by each frame.

Finally, I sought to connect this analysis of elements and frames to common challenges of understanding RJP that might affect their implementation. I used expert interviews to identify a common 'misconception' among staff at the school: that restorative justice means removing student accountability. I operationalized evidence of this misconception as the *absence* of a set of three critical elements in a given response. By comparing the relative frequencies of these elements across responses using each of the four frames, I found that (only) one frame backgrounds all three key elements: the Alternative--that is, characterizing RJP in terms of what they are not. It is notable that despite the shortcomings of this frame from a learning perspective, framing RJP as an alternative to suspension and expulsion is probably the most common justification for their use in district and citywide policy documents, popular press news stories, etc.

This analysis offers practical contributions for school leaders and RJP advocates seeking to develop effective professional development around RJP. It demonstrates, first, how conceptually complex RJP truly are, including hundreds of potentially relevant elements. It also illustrates how educators can thoroughly grasp an important facet of RJP (e.g. their use as an alternative to exclusionary discipline) and simultaneously miss important features because of the power of any given cognitive frame to foreground and invite certain elements while backgrounding or obscuring others. It also offers a contribution to the KA tradition, raising theoretical questions about analyzing learning in domains where the 'right' answer is contested, and methodological issues in bounding a knowledge domain without clear natural bounds.

Integrating Knowledge in Pieces and Interactional Analysis to examine ethical sense-making in an undergraduate engineering classroom

Ayush Gupta and Thomas M. Philip

Foundational research in Knowledge in Pieces (KiP) is grounded in empirical studies based on cognitive clinical interviews (diSessa, 1993, 2002; diSessa, Elby, & Hammer, 2002; diSessa & Sherin, 1998; diSessa & Wagner, 2005; Wagner, 2006). The associated methods of data collection and analysis have brought the productive dimensions of students' intuitive sense-making to the forefront. While certain threads of work within KiP have attended to joint-meaning making processes (Parnafes, 2007; Scherr & Hammer, 2009; Rosenberg et al., 2006; Gupta et al., 2014), these studies haven't addressed why certain taken-for-granted assumptions become salient within a context and how interaction between participants afford or limit opportunities for students to take up and build on specific intuitive understandings. In other words, they haven't fully engaged the methods of conversation and interaction analysis (Goodwin, 2007; Goodwin & Heritage, 1990; Jordan & Henderson, 1995).

A recently emergent line of research demonstrates the analytical value that is added by working at the intersections and tensions between KiP and interaction studies (diSessa et al., 2016; Gupta et al., 2016; Kapon, 2016; Umphress, 2016). We situate the current study within this line of inquiry.

The context of our study is an undergraduate engineering classroom discussion on militarized drones at a research university in the United States. This one-semester course was a requirement for all electrical and computer engineering students and was typically taken by 2nd year (sophomore) students. We transcribed the students' discussion of drones from the video recording of a 58-minute class session led by a teaching assistant. We used Philip (2011) to code taken-for-granted ideological assumptions—what Philip (2011) refers to as naturalized axioms and a social parallel to what diSessa (1993) refers to as p-prims—about the ethics of militarized drones. Additionally, we utilized methods developed in Philip et al. (2017) to examine how the interactionally achieved processes of ideological expansion and convergence shaped the salience and persistence of these stances in the participants' shared discourse.

The analytical affordances of KiP highlighted the significance of taken-for-granted ideological stances in the students' sense-making about militarized drones. For instance, a student remarked early in the discussion that militarized drones would make killing more widespread because it was more "convenient." From a KiP perspective, this argument is based on the taken-for-granted assumption that "the easier it is to do something, the more likely it is that someone would do it." Resonant with findings in the KiP literature, students also

demonstrated a range of contextually specific ideological stances that were often contradictory. As an example, one student's ideological stances were highly varied over the course of the classroom discussion: civilian deaths are inevitable, no war can be humane, people resort to war because they are too lazy to engage with diplomacy, and a government has to protect its military despite the "civilian" toll on other countries. This range of ideological stances also points to the productive potential of such intuitions when meaning-making about the ethics of various scenarios.

Our analysis shows that despite the diversity of ideological stances within and across students, these stances increasingly converged, as an interactional achievement between participants, to the position that engineers' ethical responsibility is limited to increasing the accuracy of drones to prevent the loss of civilian lives. Our analysis suggests that the process of ideological convergence made potentially expansive ideological stances less salient for some students and simultaneously more difficult to invoke for other students. Additionally, we show that marginalization of ideologically expansive stances constrained the possibilities for disciplinary and ethical learning. In sum, our paper makes a case for the analytical affordances of working at the intersections of KiP and interaction studies.

Investigating university academics' pedagogical sensemaking: A grounded dynamic perspective of teachers' pedagogical resourcefulness

Lina Markauskaite, Yael Kali, and Peter Goodyear

Studies that investigate university academics' pedagogical knowledge often assume that teachers have coherent, well-articulated 'theory-like' knowledge and beliefs (Kember & Kwan, 2000; Prosser & Trigwell, 2017). Such conceptions are rather inflexible, and academics who hold a particular view deploy it consistently across many teaching situations. The theory-like conceptualizations of teachers' knowledge are too coarse for investigating teachers' everyday pedagogical sensemaking; ignore intuitive, less articulated kinds of knowledge that are important in situated decision-making; and do not explain why teachers' knowledge observed in action often differs from their espoused views (Kane, Sandretto, & Heath, 2002). Our studies remedy this by investigating the mental resources university academics actually draw on in reasoning about course designs and teaching.

We draw on a line of theorization about people's everyday knowledge, developed in the context of physics (diSessa, 1993; Hammer & Elby, 2002), and use this mental resource view to account for university academics' pedagogical beliefs and knowledge. On this view, people have a large array of (mostly implicit) conceptual understandings of physical phenomena that they encounter in the world (diSessa, 1993) and a similarly large array of understandings of epistemological phenomena about how people learn and come to know (Hammer & Elby, 2002). By extension, we assume that people also have a rich array of mental resources for making sense of how people teach and are taught (Markauskaite & Goodyear, 2011, 2014). People develop these understandings in a variety of ways: by remembering specific situations, forming intuitive abstractions from a range of experiences, deliberatively reflecting on their understanding, being explicitly taught, etc. The grain-size of these pedagogical mental resources vary. Some can be quite small situation-specific units of meaning, similar to diSessa (1993)'s 'p-prims', and some might be broad theory-like generalizations and abstractions.

We have explored the nature of pedagogical mental resources in a number of studies, investigating university academics' sensemaking about how to design courses and teach. This paper reports insights from three such studies and offers an integrative view on the nature of teachers' pedagogical resourcefulness. We examined three contexts:

1. **General course design:** university academics' explanations of their general course design decisions (Markauskaite, Bachfischer, & Goodyear, in preparation; Markauskaite & Goodyear, 2017).
2. **Activity context:** pedagogical sensemaking of an individual teacher as she explained her everyday teaching decisions (Kali, Goodyear, & Markauskaite, 2011; Markauskaite & Goodyear, 2011, 2014).
3. **Situated action context:** the kinds of mental resources used by academics in reasoning and making decisions in curriculum innovation team meetings (Markauskaite, Bachfischer, Kali, & Goodyear, 2017).

Our results reveal that the academics tended to draw on quite different mental resources in each of the three contexts.

In the general course design context, the academics often drew on mental resources originating in formal pedagogical knowledge and intuitively-formed generalizations about knowledge, knowing, learning and teaching (e.g. Knowledge needs to be backed up with the latest evidence; People learn through analysis of their own experiences and reflections). While most drew on a range of such generalizations, these mental resources closely resembled large macro-level theory-like pedagogical abstractions.

In the concrete activity context, the academic more often articulated their intuitive sense of the micro mechanisms about how people come to understand and how they should be taught in a particular situation. For example, the teacher articulated such teaching and learning mechanisms as Reiteration (i.e. knowledge that students tend not to remember could be taught by repeating it several times); Building-on (i.e. learning should start from simple concepts or tasks and should gradually be made more complex). Many of these micro-level mental resources originated in personal experiences about how people learn and how to teach and closely resembled small intuitive, contextually-cued pieces of knowledge that we call "pedagogical p-prims".

In the situated action context, the academics often drew on knowledge of concrete experiences, affordances and constraints, such as experiences of how specific students reacted to a particular task design, or how a decision about how to teach relates to particular functions of software used on a course. In making these decisions, teachers drew on pre-existing mental resources, and also coordinated and combined various mental resources on-the-fly by taking into account affordances, constraints and other details of the situation.

Our findings suggest that academics' pedagogical resourcefulness should be reconceptualized from a perspective that acknowledges the diverse, dynamic nature of teachers' knowledge and their pedagogical sensemaking: grounded in concrete experiences and situations. Teachers' pedagogical knowledge cannot be seen as an abstract theory or generic mental process that operates solely in the head. Rather this is knowledge that is firmly entwined with the physical and social environment. Mental resources are not stable (large or small) representations, but multimodal constructs that are dynamically recombined in various ways: with each other and with affordances of the emerging situation. They provide a highly populated, dynamically evolving knowledge base for interpreting and making decisions about new situations. This grounded dynamic view of mental resources extends current Knowledge in Pieces perspectives and provides a new way for theorising and studying learning in complex, ill-structured knowledge domains, such as teaching.

Moving the goalposts: The role of values in students' shifting interpretation of simulated urban planning data

Arthur Hjorth

Recent efforts to reform social studies in K-12 emphasize, amongst other things, 'complex causal reasoning' about social issues and policy (NCSS, 2013). This raises two understudied questions: first a definitional question: what does it mean to reason causally about complex *social* issues? And second, a design question: how should we design learning activities that encourage and support this particular kind of thinking in social studies? This paper presents data from an Urban Planning curriculum unit in which undergraduate students used agent-based simulations to design cities. I find that students would often shift their interpretation of data in ways that aligned with their values, even if this meant making objectively dubious claims about the data. Taking a Knowledge-in-Pieces approach, I characterize the knowledge pieces and the process that students deployed when doing so.

In response to the first question, this paper argues that we can borrow from existing work on causal reasoning in STEM (e.g. Machamer, Darden, and Craver, 2000; Russ et al. 2008) to analyze, categorize, and assess student reasoning about social issues. However, we must also consider an additional component when studying reasoning about social issues; the role in which *values* guide the sense-making process during the active construction of knowledge. To address this somewhat unique aspect of studying reasoning about social phenomena, I propose a preliminary framework for analyzing students' thinking based on Knowledge-in-Pieces (e.g. diSessa 1993) and Michael Freeden's work on *ideology and sense making of policy (*Freeden 2005; 2008). In response to the second question, this paper borrows from a long tradition in using agent-based models as external representations of complex systems and "objects-to-think-with" (Papert 1980; Eisenberg 2003; Wilensky & Rand 2015). The fundamental principle here is that by providing an external representation of the causality in a complex system, and by providing a purpose for students to manipulate the system and see how these manipulations result in different outcomes, students can align their internal, conceptual model of the system with the external, computer-based model. Agent-based modeling-based classroom activities have been used successfully to support students while they learn to reason about complex phenomena like evolution, physics, chemistry (Wilensky & Jacobson, 2015).

Taking this work as a starting point, I designed and implemented a 3-day undergraduate unit on urban planning in which students in groups of 2-3 built and iteratively improved on virtual cities in an agent-based computer simulation. They were asked to set specific a measurable policy outcome as a goal, and then to design a city in the simulation that would meet this goal. At the end of each design iteration of their city, students were asked to assess whether they "reached their goal". This paper expands on an interesting finding from an early analysis (Hjorth & Wilensky, 2014) of these data: the goals that students set for themselves were quantitative and

easily measurable, and given the data that was available to students in the simulation, in theory this ought to be a simple yes/no answer. But when students in the unit assessed whether they had achieved their goals, they would often *shift their interpretation of the outcome data*, if the outcome was ideologically acceptable to them. For instance, students would set a goal of reducing 'commute times to less than 30 minutes ***for everyone***' (my emphasis) but would say that they reached their goal, even though they objectively did not, because 'the poorest 20% had really good commute times.' I observed similar shifts in the interpretation of data as a result of students' ideological interpretations of data in other groups.

This paper bases its analysis on the video data and students' written responses that were collected during the classroom implementation. The analysis has two purposes: first, to identify and characterize a set of different knowledge pieces that students activate when constructing meaning out of the simulation data. The second is to characterize the process of students' re-organizing these knowledge pieces, forefronting some and backgrounding others, while making sense of the simulation data, in order to facilitate these value-laden shifts in data interpretation. These findings suggest that values qua knowledge can play a productive role in students' interpretation of data, and that future curriculum development can leverage this by designing open-ended data interpretation activities with socially meaningful data.

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